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MANAGING THE INTRODUCTION OF NEW PROCESS TECHNOLOGY: INTERNATIONAL DIFFERENCES IN A MULTI-PLANT NETWORK

Marcie J. Tyre

MIT-Sloan School of Management

Revised August 1989 WP# 3004-89-BPS

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139

MANAGING THE INTRODUCTION OF NEW PROCESS TECHNOLOGY: INTERNATIONAL DIFFERENCES IN A MULTI-PLANT NETWORK

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ABSTRACT

This paper examines the introduction of new technologies in the manufacturing environment, focusing on 48 new process introduction projects carried out in eight plants in Italy, West Germany, and the United States. The paper examines regional variations in performance and identifies managerial factors which may account for these differences.

In order to understand the requirements of process change, two relevant dimensions of technological change are measured ("technical complexity" and "systemic shift"). Further, three groups of organizational response mechanisms for dealing with technological change are identified. These are preparatory (or early) search, joint search with experts external to the plant, and functional overlap within the project team.

Comparing project performance across regions, results are statistically indistinguishable in Germany and Italy. However, performance on two separate dimensions is significantly worse in the U.S. This performance gap is explained by differences in the intensity with which the three response mechanisms are used across regions. In order to understand the source of these differences, the paper examines historical differences among plants in the three regions. It is apparent that managerial choices over time have resulted in distinct sets of organizational capabilities, resources, and assumptions. These factors, in turn, have important and long-lived effects on the way plants approach technological problem solving.

INTRODUCTION: NEW PROCESS TECHNOLOGY -- PROMISES AND PROBLEMS

Example: The Case of Factory Q

In 1982 Factory Q --a large, high-volume production facility in the Eastern United States -- installed a new, high-precision machining line. The line would be the factory's first integrated, continuous operation;it promised to move the factory into the modern age of metal working. In management's view, the technology represented the future of the company, and of manufacturing in general.

In December of 1986, the author walked through the line with one of the process engineers who had worked on debugging the process. The line was in operation, but was not yet operating at full capacity on a consistent basis. Efficiency was still below acceptable levels. Product quality was passable, but no one was sure how the new line's quality performance should be assessed because engineers had never found time to install and learn to use new measuring equipment as originally planned.

During the same time period, another plant owned by the same company and located in Northern Italy also introduced a computer-integrated precision machining line, employing many of the same machine designs and producing a similar product. The line was operating at near full capacity within 18 months of installation; its efficiency and quality were among the best in the plant. By 1986, several projects were underway to develop and introduce next-generation technology to support new product thrusts. Many of the personnel involved in the successful introduction had been promoted or were managing major projects of their own.

Back in the U.S., personnel at Factory Q were quick to note that the line represented a significant step forward for the plant, and that the project had been successful in ways that its efficiency ratings did not capture. Nonetheless, the experience had devastated the plant. For four years, the new line had drained engineering and maintenance resources from other parts of the plant; it demanded continuing inputs of time and capital, and had not begun to pay back the sizable investment it represented. In the interim,

corporate management had determined that Factory O was probably not ready, after all, to become the high-performance, automated producer they had hoped it could be. The reality facing plant personnel was that the factory was likely to be closed.

The Challenge of Technological Changes

This case is repeated, often in less extreme form, too frequently in too many factories. When companies introduce new manufacturing processes, the real failures are not those introductions which are quickly rejected by the organization, but those which create a persistent drain on human and capital resources without yielding competitive benefits. One major U.S. study found that the difficulties of introducing new manufacturing equipment frequently result in productivity losses equal to or exceeding the original cost of the equipment, and that the disruptive effects can persist for two years or more (Chew, 1985; Hayes and Clark, 1985). Persistent problems can have serious competitive implications as deliveries, reputation, and market share slip. Further process change becomes impossible, while competitors' process technologies move steadily ahead.

These concerns are particularly relevant in the United States. Jaikumar (1986), for instance, argues that U. S. managers "are buying the hardware of flexible automation -- but they are using it very poorly. Rather than narrowing the competitive trade gap with Japan, the technology of automation is widening it further" (page 69). Thurow (1987) blames "America's poor productivity, quality, and trade performance" squarely on inferior capabilities in introducing and using process technology (page 1660). According to the Manufacturing Studies Board, U.S. companies need to "reemphasize process improvements -- selecting, using, and implementing available manufacturing technologies -- as a critical competitive weapon." (Manufacturing Studies Board, 1986:17)

Yet despite evidence of serious problems, little is known about how managers can improve their organizations' ability to utilize new technology. Much of the existing research on process innovation and diffusion has focused on the decision to adopt new technology, rather than on the process of

learning to use a new technology once it has been brought into the organization (Kimberly, 1981; Rogers, 1983). Most of the existing research on the "implementation" stage of the diffusion-innovation process focuses on developing organizational attitudes and receptivity to change[1]. This is a useful first step, but it fails to illuminate the behaviors needed to identify and address the problems and uncertainties involved in technological process change.

Process Change as Technological Innovation at the Plant Level

The premise of the paper is that the success of a new process introduction is not just a function of organizational receptivity. Successful technoligcal change also requires active organizational efforts to adapt the new technology, the existing manufacturing system, and the organization itself to a new set of demands (Abernathy and Clark, 1985; Leonard-Barton, 1987; Van de Ven, 1976). Consequently, new process introductions often require considerable problem solving and even innovation at the plant level (Kazanjian and Drazin, 1986; Rice and Rogers, 1980).

This paper examines the management of process change at the level of the individual project and in the larger strategic perspective. It identifies organizational mechanisms for adaptation and analyzes their impact on the success of new introduction projects. Further, the paper explores whether national or regional differences in project performance and project approach exist within a single multi-plant network, and seeks to identify the causes of observed differences. The paper suggests that managerial choices that shape organizational assumptions, technical capabilities, and external linkages amount to long-term strategic decisions. These choices influence performance levels and technological options well into the future.

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[1] This research tradition is represented by two streams of research. First, much of the early "implementation" research examined the different requirements of various stages in the innovation process. Many authors concluded that implementation, as distinct from development, calls for relatively tight forms of managerial control (Duncan, 1976; Sapolsky, 1967; Zaltman, 1973). Another research stream focuses on creating organizational or worker receptivity to the new technology (e.g. Majchrzak, 1988; Nutt, 1986).

The balance of the paper is organized in five parts. In Part I, I draw on existing literature to identify three principal organizational response mechanisms for dealing with technological change. Part II describes the research methodology and the variables used in the analysis. Part III examines the data on project attributes and project success, and compares results across regions. In Part IV, I discuss some of the forces which may explain the differential success of introduction projects in various regions. Part V presents conclusions and suggestions for further research.

I. ORGANIZATIONAL RESPONSES TO TECHNOLOGICAL CHANGE

An organization's proactive efforts to deal with change can fall into one of two broad categories. First, the organization can prepare. By gathering information and making necessary adjustments early, before it undertakes the change, the organization decreases the uncertainty it faces and increases its ability to plan for or control events. Second, the organization can increase its ability to adapt to unexpected events once change has occurred. This involves developing ways to capture, transmit and use new information through increased coordination and feedback in "real time" (during task execution). Theorists argue that if the organization facing change increases neither preparatory efforts nor real time coordination and feedback, it has no choice but to accept a lower level of performance (Galbraith, 1973; March and Simon, 1958; Thompson, 1967).

Based on the literature on change in organizations and on initial fieldwork, I identified three "response mechanisms" which enable organizations to adapt, either in advance of technological change or during task execution. These are: 1) preparatory, or early, search undertaken before the new technology is put into use; 2) joint search during the startup process with technical experts outside the factory, and 3) functional overlap between engineering and manufacturing groups at the plant level.

1. Preparatory Search involves the investigation, modification, or "reinvention" of the new technology and relevant aspects of the receiving organization before the technology is installed in the factory (Rice and Rogers, 1980; Rogers, 1983; Van de Ven, 1986) This may involve adapting

existing manufacturing systems, routines and procedures (Bright, 1958; Chew, 1985). Coordination with (internal or external) developers of process equipment is an important aspect of preparatory search, allowing the mutual adaptation of source and user during the early phase of the project (Leonard-Barton, 1988).

The second and third response categories both involve real-time mechanisms for adapting to problems and opportunities which develop as the organization gains experience with the new technology:

2. **Joint Search** involves coordination with knowledgeable individuals from facilities or organizations external to the manufacturing plant. The notion of joint organizational search stems from the concept of an "organization set" (Evan, 1966; Thompson, 1967) or, more specifically, a unit's "technological organization set". The latter can be defined as a coalition of suppliers of technology, equipment, components, or information. Research suggests that joint problem solving among members of the relevant technological organization set can account for "a major part of the company's problem solving capability with respect to the new technology" (Lynn, 1982:p. 8; see also Ettlie and Rubenstein, 1980; Imai, Nonaka and Takeuchi, 1985)

3. **Functional Overlap** involves linking relevant functions within the organization to create "overlapping" subsystems or multifunctional teams for dealing with change (Galbraith, 1973; Gerwin, 1981; Landau, 1969). In the manufacturing environment, key functions include the plant technical or engineering activities and direct management of production output. Tighter linkage between these areas moves the locus of decision-making closer to the source of relevant information, and therefore increases the organization's ability to respond to uncertainty (Beckman, 1986; Perrow, 1967).

II. RESEARCH METHODOLOGY

Methodology and Data Gathering

The introduction of new process technology into existing plants is a long

and complex process. Progress may be affected by multiple, often subtle factors related to the project and its context. Understanding these factors typically requires in-depth clinical analysis of individual cases. However, in order to identify patterns and systematic variations among projects, this complexity must be compressed into a few standardized measures.

To meet these competing demands, I collected three kinds of data: descriptive information about projects, their history and contexts through open-ended and semi-structured interviews; specific data on project characteristics and outcomes through a written questionnaire; and documentary evidence about plant operations and projects undertaken from company archives.

Clinical field work began with open-ended interviews of managers and technical staff at the corporate and division levels. Exploratory interviews at each plant were used to examine salient dimensions of the technological change process, and to identify new process introduction projects and principal informants.[2]

Data on each project were gathered through a series of semi-structured interviews with principal informants and other project participants. Personal interviews were also used to introduce a written questionnaire which was filled out be each principal informant, and to collect questionnaires and follow-up comments four to six weeks later. This process resulted in 100% response rate. Interviews lasted from one to four hours, and each respondent was interviewed several times over the course of a year or more. Information was corroborated by managers at the plant and division levels. This iterative method of data gathering allowed new insights derived during the course of the research to help guide analysis and interpretation of the data collected.

Site Selection

[2] In each case the principal informant (also referred to as the "project manager") was identified during early field work as the person who had the "most direct, day-to-day responsibility for bringing the new technology up to speed in the factory". Other project participants were identified both by plant management and by principal informants.

Research was undertaken at a single leading manufacturing company, and involved eight plants located in the United States, West Germany, and Italy. The Company operates in a single, well-defined industry (precision metal components). It is the world market leader in its industry in terms of market share and reputation for product quality. Competition in the industry focuses on consistent precision quality as well as cost, and senior managers view the Company's superior manufacturing capabilities as their primary competitive tool. These capabilities are supported by extensive in-house process development activities. New machine tools and manufacturing processes are developed at the central Process Development Laboratory and in several divisional technology centers. Process technology is also purchased from outside vendors.

The Company is organized geographically, and operations in different countries are run as separate divisions with local management. This study was carried out in three major divisions within the Company -- West Germany, Italy, and the United States -- and involved two to three plants in each division. These eight plants represent a cross-section of the Company's operating facilities. They include one large factory in each division manufacturing a core part of the product line and often located close to the division offices and technology center. In addition, the sites chosen include more remote and specialized facilities. In each division, the plants studied include one operation judged by local management to be "very capable", and one judged to be less able technologically.

Limiting the research to one global, single-product corporation had several benefits, including controlling for most industry, product, and market variations. The design also facilitated access to detailed and confidential information about projects and their historical, technological, and competitive contexts (see Rogers, 1983; p. 361; Graham and Rosenthal, 1986). On the other hand, I anticipated that, even within the same company, managers in different countries might take different approaches to the introduction of new process technology (Jaikumar, 1986; Lynn, 1982; Clark, 1988). Individual divisions had developed along very different lines. The amount of local autonomy and the level of participation by divisions in

Corporate-level decision making has varied significantly among divisions and over time.

Given this background, the Company offered an excellent opportunity to examine national or regional performance variations in a multi-plant network and to examine some of the managerial differences underlying those differences. On the other hand, given the small size and restricted nature of the sample, it is not possible to generalize from this study to more general national or regional differences in the management of technology. Nor is it possible to determine from the data presented here the influence of national or regional contexts on the managerial factors observed.

The cross-cultural aspect of the research raised important issues of construct validity given cultural differences. This was dealt with through extensive field work aimed at developing measures and employing vocabulary appropriate to the different contexts studied.

Sample Selection

The sample of projects studied includes all of the new process introductions identified where the technology was "new" in some way to a particular factory and which:

1) were undertaken during the last four years and completed or nearing completion at the time of the study;

2) represented a total capital investment of greater than $50,000 (in constant 1986 U.S. dollars); and

3) involved participants who were available for interview.

The sample includes a spectrum of technological process change, from improved versions of existing equipment to introductions of novel technologies and production systems. Production technologies include metal turning and precision machining equipment, assembly and inspection systems, thermal treatment and metal forming equipment, and handling systems; the

range of technologies introduced in each of the three divisions is comparable. Four to eight projects were studied in each plant. A total of 48 introduction projects comprise the sample.

Variable Definition

Quantitative measures were developed for each of the following:

(1) Project Attributes: The size and nature of the technological change, relative to existing technology and to past practice in the specific user environment;
(2) Response: The organization's response to the change, in terms of the three mechanisms identified in Part I;
(3) Outcome: The success of the introduction project, in terms of the startup time required and the operating benefits achieved.

Variables are described below. Further details on variable definition and measurement are presented in Tyre and Hauptman (1989).

Project Attributes

Because projects varied widely in the amount and nature of the change involved, it was necessary to measure and control for these project attributes. Measurement of project scale was straight-forward and was based on total investment in new equipment, tooling, and other capitalized items (stated in constant 1986 U.S. dollars). On the other hand, controlling for the technological challenge involved was more complex. Six aspects of technological change were derived, based on the literature on innovation and diffusion combined with early field work. These relate to the the newness of the technology and the nature of the change it represents in a specific plant environment (see Appendix 1). Data were gathered through twenty-four separate questionnaire and interview items; this was reduced to six aggregate scales relating to the amount and nature of change. Reducing the data in this way increased its statistical reliability and interpretability in further analyses.

Aggregate scales then served as input for exploratory factor analysis to identify underlying dimensions of process change. The factor procedure employed principal analysis with orthogonal factors (Jackson, 1983; p. 147). Analysis revealed convergence around two factors, accounting for 53% of the variance in the aggregate scales of technological change[3].

The first factor, labeled technical complexity, measures the number, novelty, and technological sophistication of new features and improved concepts introduced (such as tooling, measurement and control systems). The second factor, called systemic shift, is the degree to which the new equipment or system introduces fundamentally changed manufacturing tasks or operating principles to the plant. Projects rated high on systemic shift represent departures from accepted manufacturing approaches, such as moving from traditional metal removal processes to near-net-shape forming technology, or moving from reliance on buffer stocks between operations to an integrated just-in-time flow of manterials[4]. When both technical complexity and systemic shift are high, the introduction represents a "radical" shift in the technology of the factory. The practical meaning of this distinction is illustrated by managers' comments about projects which were rated particularly high or low on these variables, as shown in Figure 1.

FIGURE 1 ABOUT HERE

Organizational Response Mechanisms

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[3] Factor results are shown in Appendix 2. Oblique roations were also tried, however they did not improve results significantly. Similarly, inclusion of a third factor does not improve explanatory power. While the percent of variance explained is not large, it is considered satisfactory for exploratory work and appears consistent with findings based on clinical data.

[4] This dichotomy can be traced back to Perrow (1967); similar distinctions have been suggested by Abernathy and Clark [2] and Tushman and Anderson (1986). The measurement and implications of the distinction described here are discussed in Tyre and Hauptman (1989).

1. **Preparatory search**: The intensity of search and adjustment undertaken before installation of the new process was measured by four interview and questionnaire items detailing the involvement of factory personnel in proposing and developing the technical features of the new equipment or system, including early development and testing activities carried out by factory personnel. Items and scale reliabilities are shown in Appendix 3.

2. **Joint Search**: Measures of the intensity of joint search are based on four interview and questionnaire items describing the role of personnel from outside of the factory and the importance of their contributions during the start-up process. (See Appendix 3.)

3. **Functional overlap** was measured by the number of lateral linkages between plant engineering and production personnel used in the project. Eight possible linkaging mechanisms were identified. Since linkages are adopted cumulatively (Galbraith, 1973), a higher score represents a greater intensity of integration between functions. Primary information came from (1) participants' sketches of the "people and project structure" on the written questionnaire and (2) participants' descriptions of the involvement and contribution of various players in the problem solving process.

Project Outcome

Multiple measures of project outcome were investigated; two principal measures are discussed in this paper.

1. Startup Time: The elapsed time between installation and productive use of new process technologies has important economic and competitive implications for the firm (Gunn, 1987; Thurow, 1987). Startup time influences factory efficiency and delivery performance, the ability to carry out other projects, and career growth of project participants. The following definition of startup time is used to reflect the idea that the initial startup period, during which disruption to ongoing operations is often significant, is more costly (in terms of resources used and opportunities foregone) than the later period, when the technology is operating productively but is not yet fully debugged (Chew, 1985). Startup time is the sum of:

1) **Initial startup period**: the elapsed time in months from delivery of the equipment until parts are being made in production mode; plus

2) **Introduction period**: the elapsed time in months from delivery until the new process operates at acceptable levels or until the the project is considered complete.[5]

Information came from project schedules and key dates reported on the written questionnaire, with corroboration from project documentation and plant management.

2. Operating Improvement: Managerial choices are expected to affect the effectiveness of the new technology as well as the efficiency of the introduction process (Leonard-Barton, 1988; Rogers, 1983). Data on improvements in operating performance comes from three interview items

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[5] This does not indicate when (or whether) the technology reaches fully satisfactory levels of performance. Performance at project completion may differ significantly from original expectations or from current requirements.

concerning the usefulness of the technical solutions implemented, the degree to which technical objectives of the project were met, and the level of operating reliability achieved. (Cronbach's alpha test of scale reliabilty = .86) This approach to measuring project performance is consistent with studies of R&D projects, where judgmental assessments of operating improvement have proven reliable (e.g. Allen, 1977; Allen, Tushman & Lee, 1979).

Variables can be organized into an operational model of process change, depicted in Figure 2.

FIGURE 2 ABOUT HERE

III. RESULTS

Project-Level Differences: Project Attributes, Organizational Response, and Project Outcome

The first question explored is the relationship among project attributes, organizational responses, and project outcomes for the sample as a whole. Table 1 shows the correlation matrix for the variables introduced above, and Table 2 shows regression results. Equations [I] and [III] in Table 2 examine the effect of project attributes on outcomes; they provide some initial support for the validity of the measures used here. Project attributes by themselves explain a significant amount (33%) of the variation in startup times; however they do not explain observed variations in the level of operating improvement achieved.

TABLE 1 ABOUT HERE

Considerable insight is gained by taking into accoint variations in the use of organizational response mechanisms. In the regression for startup time (Table 2, equation [II]), the coefficients of preparatory search, joint search, and functional overlap are all negative and significant (at $p=.05$). That is, greater use of these mechanisms is associated with shorter startup times. Moreover, the inclusion of response mechanisms in the analysis appears to give a clearer picture of the effects of systemic shift and project scale.

Results of the full regression for operating improvement (equation [IV] in Table 2) also suggest that organizational responses play an important role in successful introductions. Higher level of preparatory search and joint search are both associated with higher ratings of operating performance. The major difference is that the coefficient of functional overlap, while in the expected direction, is not statistically significant[6].

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[6] This result was not expected and is explored in more detail in Tyre and Hauptman.

TABLE 2 ABOUT HERE

These results suggest that preparatory search, joint search, and functional overlap are important mechanisms for coping with technological process change. They appear to contribute both to the speed with which manufacturing facilities introduce new process technology, and (with the possible exception of functional overlap) to the degree of operating improvement achieved. (It should also be noted that fast startups are, in general, associated with high levels of operating improvement ($r=-.63$; $p<.05$). Therefore, it is not surprising that the response mechanisms identified appear to enhance performance on both measures.)

Regional Differences: U.S. versus Europe

The next step in the analysis is to compare project performance of plants in the U.S., Germany, and Italy. As shown below, analysis revealed systematic differences between projects undertaken in U.S. plants and those in Germany and Italy. On the other hand, the German and Italian subsamples were statistically indistinguishable on the dimensions examined. Therefore, in the following analysis I treat projects undertaken in Germany and Italy as a single European sample. Underlying similarities and differences in the two subgroups are discussed in Section IV.

The U.S. plants took longer, on average, to introduce new process technology than did European factories, and they reported lower levels of operating improvement. Table 3 shows summary statistics for the two regions. As noted, no consistent differences were discovered between divisions in Europe.

TABLE 3 ABOUT HERE

These results are examined in greater detail by means of regression analysis. In Table 4, a dummy variable indicating the region (U.S. or Eruope) in which the project took place is entered into the regressions for

startup time and operating improvement. The new variable is coded 1 for projects undertaken in the U.S. and controls for any "regional effect" on project outcomes not explained by other variables in the analysis.

TABLE 4 ABOUT HERE

Equations [I] and [III] in Table 4 show regional differences after controlling for measured project attributes but not controlling for variations in organizations' responses to change. On this basis, the U.S. project locus is associated with significantly poorer project outcomes. Projects undertaken in the U.S. took longer to complete than did projects in European plants by an average of 8.8 aggregate months, or an increment of almost 45 percent. The "U.S. effect" on operating improvement is comparable; at the mean, new equipment and systems introduced in the U.S. were rated 48 percent below those introduced in Europe in terms of operating improvements achieved.

Once organizational responses are taken into account, however, the association between regional locus and projet success becomes statistically insignificant. The addition of preparatory search, joint search, and functional overlap reduces the effect of the U.S. dummy variable on startup time by approximately two-thirds (Equation [II]), and decreases its effect on operating improvement by approximately one half (Equation [IV]).

Organizational Responses to Change in Europe and the U.S.

This analysis suggests that while the U.S. plants studied did tend to perform poorly on process introductions relative to their European counterparts, a large part of the gap is accounted for by the tendency of project teams in the U.S. to respond somewhat less vigorously to technological change, both before and after the actual installation of the new equipment. This argument is further supported by comparing the relationship between project attributes and organizational response variables across the two regions (Table 5). U.S.-based project teams were less likely

than their European counterparts to respond to particularly challenging projects with intensified preparatory search or joint search. In fact, there is a marked tendency to undertake less preparatory search in the face of large-scale projects than in smaller introductions[7]. Further, while the use of functional overlap in U.S.-based projects is strongly associated with the degree of systemic shift undertaken, absolute levels of functional overlap in the U.S. are still relatively low. In Europe, six projects rated either five or six on functional overlap (out of a possible high score of 8), while no U.S. project rated higher than four. Conversely, five projects in the U.S. had an overlap rating of 0 (the lowest possible score), as opposed to one such project in Europe.

V. ANALYSIS OF REGIONAL DIFFERENCES

Regional differences in project performance cannot easily be attributed to underlying differences in the products produced (which are closely comparable across regions) or the nature of the projects undertaken: as shown in Table 4, significant unexplained performance differences persist even after controlling for the size and nature of the change. Rather, results suggest that there exist managerial differences across regions which influence teams' use of the response mechanisms examined here. This finding raises important questions about the source of regional differences in search activities and, in turn, in the ability of the plants studied to introduce new manufacturing technologies.

The following analysis seeks an answer in the historical evolution of the manufacturing organization and its process technology in each division. As discussed below, managerial choices made over time dictated that regional operations evolved along different lines, acquiring different capabilities and operating assumptions. Further, these attitudes and capabilities, once created, proved to be long-lived and resistant to change: starting in 1985

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[7] One reason for this surprising finding is that, in many cases, large-dollar projects involved the introduction of new equipment from the Company's central Process Development Lab. U.S. project managers frequently expressed the belief that it was the Lab's responsibility to fully test their equipment and to deliver working production machines. This issue is discussed later in the paper.

(the year before initiation of this study), management at the corporate and division levels began taking vigorous action to address what they viewed as historical weaknesses in U.S. operations. However the evidence suggests that embedded organizational constraints continued to affect efforts to introduce new process technology.

As background, it is important to note that these differences developed within particular social, political, and economic contexts at national and regional levels. Both specific managerial decisions, and the impact they had on operating units, can be examined within that larger environment. However, for the purpose of this paper I shall focus on specific intrafirm comparisons; I do not examine their relationship with national or cultural variables.

Organization Structure and Technology Strategy

1. European Operations: Local managers in the Company's European divisions have a high degree of autonomy over operating decisions. However, strategic decisions relating to manufacturing operations and technology are made by centralized management committees composed of senior managers from division and central staffs. Product line rationalization, as well as process and product development, have been aggressively pursued and centrally coordinated through this vehicle in all European operations since the mid 1960's.

As a result, there has been a coherent strategy for process development in the European divisions for almost 20 years. In the early 1970's, the Company's central Process Development Laboratory[8] introduced the first generation of proprietary "ABC" machine tools, which incorporated new concepts for precision metal finishing. German and Italian plants soon adopted the technology, completing hundreds of introduction projects. Describing the process, one senior manufacturing manager observed, "It took a long time to debug those early machines and we had many problems. But we learned a huge amount about the equipment, and about how to bring new

[8] The Process Development Lab is located in a different European country. It is romote in location and language from any of the divisions studied.

technology into the plants."

In the late 1970's, the Development Lab introduced the second generation of "ABC" machine tools. The new line was based on existing machining concepts but incorporated a proprietary microprocessor control system. This development enabled European plants to introduce one standardized control technology from the start. As a plant manager explained, "We made sure that not one machine was introduced that did not have the possibility to communicate with other machines on the floor."

In the early 1980's, the Company's development thrust turned to linking separate machines on the shop floor. The result was the introduction in German and Italian plants of a centrally-controlled, fully integrated machining and assembly system capable of 24-hour low-manned operation. Finally, in the latter 1980's the objective has been to develop more flexible integrated systems, where appropriate, for greater market responsiveness in low-volume product types.

2. United States Operations: Recent history in the Company's U.S. division differs sharply from the above. Until the mid-1980's the U.S. division enjoyed full autonomy over local policies and operations, maintaining an arm's length relationship with the parent Company and its centralized management committees. The result was the development of a different environment for technological change.

Until 1985, the U.S. division treated its plants as decentralized, independent profit centers. There was very little product line rationalization or coordination of process development. According to the engineering manager at one U.S. plant, "Until recently, there was no real long-term planning on the subject of manufacturing processes and equipment. Every capital request was reviewed in isolation."

While a number of early examples of internally-developed "ABC" machine tools were introduced in the early 1970's, process investment slowed in later years. When factories did buy new capital equipment they tended to eschew the second-generation, microprocessor-based "ABC" machines, relying instead

on external equipment vendors and traditional manual technology. There were some localized efforts to integrate separate machining operations, but plants ended up with multiple, incompatible machine control systems. Further, while the German and Italian divisions maintained active equipment development efforts to complement work at the central Development Lab, the U.S. equipment development center had been closed in 1972. With that move, many of the functions of the division-level technology group had been discontinued.

U.S. factory operations during the 1970's and early 1980's were characterized by fragmented product assortments and low quality levels relative to the Company's standards in its other divisions. During this period, as one division manager described it, "The U.S. division had been making money, but in a short-term mode. They were not investing in technology or productivity."

Organizational Assumptions and Technical Capabilities

Partly as a result of the pattern of decisions described above, both the German and Italian divisions boasted strong installed bases of process technology, strong manufacturing capabilities, and technically capable personnel which were largely lacking in the Company's United States division. Productivity growth in Europe had averaged 7% per year between 1970 and 1985, whereas the comparable figure in the U.S. was 1.5%. Similarly, while local variations prevent exact comparisons, U.S. plants were judged by Company management to be considerably behind their European counterparts in terms of defect and quality levels, and in measures of operating efficiency such as cycle time and machine set-up time.

Following the introduction of coordinated Company management of U.S. operations in 1985, differences between regions in specific manufacturing performance indicators began to narrow. However, patterns and assumptions developed during the earlier period continued strongly to influence the way in which new process technology was introduced into plants.

Most important appears to be a relatively weak organizational infrastructure for continuous process development and refinement. In the U.S., such activities and their results were not tracked consistently before

1986. As one senior manager in the region expalained, "There were other ways to show a profit besides worrying about operating efficiencies." According to a manufacturing engineer who had worked in both European and North American plants;

In America, it's easy to get plant engineers to start working on large projects, with formal project management structures, but it's extremely difficult to keep attention focused on the details over time. People tend to drift away to other problems when the work is only half done, leaving all the little tasks that actually mean the difference between success and failure in a new system.

In both Italy and Germany, plant-level engineers spent a great deal of time developing and achieving annual improvement plans. These were formally specified in terms of productivity, quality, and other measures of operating effectiveness, and monitored at the division (and even corporate) level. While improvement activities were managed differently in the two European divisions, plant-level personnel in both countries generally had several process improvement projects ongoing at any time. These "miniprojects" frequently involved iterative development and testing of new tooling or devices in conjunction with the division's local technical center or (especially in Italy) with outside suppliers. According to one senior technical manager;

When we say that European plants are specialized by product line, we mean that they concentrate not just on making those parts but are also responsible for both product and process development. Each division is a development center for a specific technology. Underlying this is a strong requirement -- and will -- to improve on what now exists. While we rationalize product lines, we integrate technical ideas across plants and across divisions.

As this quote suggests, and important difference between the two regions concerns the way in which project teams used external sources of expertise, both inside the company and outside it, to explore technical problems and potential solutions. While counterexamples exist, U.S. project teams tended to expect to purchase solutions from equipment vendors or component suppliers, whereas project teams in Europe were more apt to use outsiders as a resource for continued development of a given item. This contrast is apparent in the way project teams in the different regions viewed the

development of new tooling to support new process technology. In Europe, tooling development typically was viewed as a critical task requiring the combined knowledge of both plant-level engineers and tooling experts from internal and external suppliers. For instance, one project leader in an Italian plant explained that;

We identified very early what would be the most critical problem to solve: developing tooling of sufficient precision to allow us to take advantage of the new CNC technology. And we devoted a great deal of effort to a thorough tooling study. An important part of this process was working with the tooling experts at the equipment developer -- the real workers who use those machines -- to understand how to utilize this new technology.

Developing tooling systems which were not just usable but optimal was considered one of the factory's regular responsibilities, and was a focus of attention before, during, and after the introduction itself. In several instances, this emphasis blurred the exact boundaries of the introduction "project" itself. As one German project leader told me, "You really can't call all the continued effort at tool optimization part of the project--that's something we are always doing, on all our equipment."

In contrast, many U.S. project managers expressed the view that the most efficient approach was simply to purchase a satisfactory tooling package from the equipment vendor, thereby avoiding the need to invest time in tooling development. One manager attributed the problems which plagued a particular introduction to the fact that the machine had not been purchased along with a full complement of tooling from the vendor. Another project manager explained that the external supplier had delivered a tool set "which worked right off the bat. It never presented a problem, so we never had to run any more trials or ask for changes." He was extremely satisfied with the arrangement.

The notion that technology can be purchased "off the shelf" extended to new manufacturing equipment from the Company's Process Development Lab. As a senior U.S. manufacturing engineer explained;

The new machines from Central Lab require a shift in skills and operating procedures -- but that is all provided. You don't need to have all the knowledge in place because the machines come complete with hardware and

software, reference manuals, and service engineers from Central to do the training and initial set-up. Once you learn how to push the buttons, these machines are quite simple to use.

This expectation, however, was not borne out in practice. In almost every instance where equipment from the central Lab was introduced into a U.S. plant, project participants complained that the machine did not in fact operate according to specifications, and that the service engineers who performed initial set up did not complete the task of debugging the equipment or training local operators. Engineers from the Process Development Lab, in turn, argued that U.S. managers and technical personnel expected Lab engineers to run their equipment for them. While there were notable instances in which U.S. project participants invested heavily in joint search with equipment vendors, all but one such case involved vendors external to the company and technical features which were relatively well-developed (low to medium technical complexity).

While European project participants also complained about the lack of technical support from the central Lab, they simultaneously stressed that part of the development responsibility must rest with the factory. As a divisional manager explained;

Engineers in the Labs are experts in the machine technology, but we are the ones who really understand the manufacturing process. Therefore, to take a machine which meets the basic specs and make it respond to all our requirements --that's the job of the factory.

Engineering Infrastructure:

The different attitudes and capabilities displayed in Europe and the United States appeared to be rooted in different engineering "infrastructures" in the two regions -- that is, in contrasting approaches to the organization and development of technical talent in the manufacturing environment. Although Germany and Italy differed in many aspects of their engineering infrastructures, both divisions shared common themes which were absent in the U.S.

1. Italy: In Italy, according to the division's director of manufacturing

technology;

The word "engineer" is hard for us to define. There are at least two possibilities this can refer to within the plant. First and foremost, the backbone of this organization is the "shop floor engineer". He is in the line: generally a foreman or assistant foreman. He is responsible for production and quality, as well as for cost and quality improvements. He also has hands-on responsibility for new projects. Second, there are factory technical offices. These are the future-oriented engineers; they support production people in ongoing operations but they also develop new kinds of solutions. But they never have direct project responsibility for new process introductions. It's important that line managers have responsibility for new technology from the start.

Indeed, in many instances it was difficult to measure the degree of functional overlap in Italian projects because respondents sometimes had trouble distinguishing engineering and production as separate functions. In several cases, an individual was described as having direct responsibility for manufacturing, but also maintaining a seat in the plant technical office.

Personnel development in the Italian division includes considerable job rotation between direct manufacturing supervision and the plant technical office. All levels of manufacturing management and technical experts go through a "spiral of rotation" which begins with machine attendance and generally includes experience in a variety of manufacturing and project situations. Promising individuals also move between the division technical center and the factories. While the Italian technical center itself is very small, its staff works closely with plants to understand their needs, and with outside machine shops or component suppliers to design and realize new ideas for machines or devices for use in the plants. In addition, people move between plants over the course of their career, creating a basis for sharing knowledge and experience among plants in the division. The Italian division was noted for its ability to utilize and build on existing knowledge through extensive in-house training, team assignments, and cross-fertilization among areas and plants.

Many observers within the Company pointed to the deep capabilities developed by this system at the level of production setters, supervisors, mechanics and maintenance people. As the Company's director of manufacturing described it;

Our Italian plants put less emphasis on the pure engineering excellence of their people than do, say, the Germans; but their strength is in the very careful, conscious management of their technology. They have created a very high level of interest and ability among all their people.

The outcome, as one U.S. engineering manager remarked, was that;

The Italians are wonderful at making all kinds of process refinements--and it's because of the management there, not the product line or anything else. They love to "fiddle" with their equipment. But it's not a game--they are very conscientious about applying their knowledge to their operations. You take a machine which we consider great, but they make lots of little innovations and end up running twice as much product on it.

2. Germany: In the German division, the plant-level engineer is conceived quite differently. Engineering is organizationally distinct from production management and generally reports directly to the plant management. Many plant-level engineers have formal engineering degrees, as distinct from the apprenticeship undertaken by operating personnel. Indeed, there are important distinctions within the engineering office based on individuals' formal technical training.

Formal responsibilities in the plant are clearly bifurcated. Engineers are directly responsible for cost and quality improvements. The chief engineer is the formal project leader for planning and administration of new process introductions, and implementation is generally the direct responsibility of a process engineer in his or her group. Production managers, meanwhile, are responsible for meeting output targets in terms of quality and quantity. They are also expected to support the engineers' improvement efforts, principally by allocating people and development time to improvement and introduction projects.

However, these clear distinctions often break down -- or are actively broken down -- in actual operating procedures. Two of the three plants studied in Germany presented exceptions to the standard organization structure. One plant was composed of several small shops or subfactories; within them, engineers reported to manufacturing shop managers. In fact, in at least one of these shops, the production manager was also the chief

engineer. In another plant, in addition to the "real" (degreed) engineers working in the technical office, there were also engineers who "sat on the production floor" in each department and reported to manufacturing managers.

Further, there was considerable technical expertise among production personnel at all levels. Production managers typically were shown considerable respect by degreed engineers on the basis of their technical know-how. As one degreed engineer explained, "The manufacturing supervisor and the department manager are really engineers too -- they are the floor engineers." While their technical capabilities varied, manufacturing managers at this level all received some formal technical training, and they were the first ones to respond to technical problems on the line. Indeed production department managers frequently came from the plant's engineering office. In many cases, junior engineers in charge of introduction projects reported in a sort of informal matrix arrangement to the production department manager.

Relative to Italy, technical personnel in Germany were less likely to rotate among plants or between plants and the division technical office. On the other hand, considerable efforts were made to link technical development activities at various facilities. First, five of the seven plants in the division (including two of the three plants studied here) were located in a geographically centralized "complex" along with the division headquarters and technical center. The division technical staff, which was several times the size of the group in Italy, was responsible for designing, building, and helping plants to implement new equipment and systems. Especially in plants located in the central complex, there was considerable interplay between plant engineers and engineers at the technical center. Further, factory personnel with particular areas of expertise or experience were often consulted or even borrowed for projects undertaken in other plants in the complex.

Whereas Italy was known within the Company for its penchant for "fiddling" with production equipment once it was on the floor, Germany was famous for doing a great deal of technical preparation of both the new

equipment and the existing factory before attempting a new introduction. While this did not always occur (as measured by levels of preparatory search in the projects studied) it consistently was recognized as being of utmost importance. One project leader explained;

This was one of our most successful introductions because we worked explicitly to identify all the most important unknowns, and to develop solutions, **before** the equipment was shipped or, in many items, even before it was ordered. If you really think about it, you can identify and address 95 percent of the hard issues beforehand.

3. United States: The formal organization structures of U.S. factories resembled the German pattern, with separate engineering departments reporting to the plant manager. However, with the exception of the small subcomponent plant studied, informal integration of technical priorities and production requirements was often more difficult to attain. In several instances, plant-level engineers blamed delays in introducing new equipment on the difficulty of getting the production manager to set aside time for operator and supervisor training or for on-line testing of tooling or devices. Manufacturing managers, meanwhile, frequently attributed disruption and startup delays to the absence of engineering support during startup and later debugging of the new equipment.

Further, many individuals in the company argued that engineering capabilities in U.S. plants were too thin. In the U.S., formal and in-house technical training or personnel development through job rotation received much less attention than was true in Europe. Plant-level engineering capabilities, and the relationship between engineers and production people in the plants, varied widely. Unlike the situation in European divisions, high turnover among engineers was a frequently-cited problem. As one senior manager said with dismay, "Many of the engineers in these plants are not even from our industry. They do not really understand the products and processes involved."

In addition, managers and technicians on the plant floor often lacked necessary technical skills. According to one European engineer who had worked in various U.S. operations;

The production supervisor is the place where there is very often a big gap. In too many cases, the supervisor does not have sufficient understanding of modern production technologies, so he ends up relying of operating people for process expertise. Sometimes the operators have long experience and special aptitudes, but sometimes that is not the case. So it can be hard to carry out big projects successfully.

Another engineer, who had worked in the Company's U.S. division for some forty years, pointed to serious erosion of process capabilities among the "engineering backup" in local factories. In his view,

The operator level is not, or should not be, what is critical. Productivity of both old and new machines comes from the engineering backup in the plants -- the engineers, maintenance people, and supervisors. That small group has got to be the organizational intelligence between management and operators. They have to be able to teach operating people, to guide them to focus on key problems, not just rely on operators' expertise. The competence of that group and how it is cultivated is the key to the ability to bring in new machine technology.

V. CONCLUSIONS

This paper has analyzed the performance of new process introductions undertaken by a single technology-based company operating in both Europe and the United States. The analysis has suggested that the observed regional differences in performance can be traced, in the short run, to underlying differences in the way project teams respond to technological change. The response mechanisms identified -- preparatory search, joint search, and functional overlap -- were shown to support improved project performance in terms of startup time and operating improvement. As demonstrated, project teams in Europe and the U.S. differed in their propensity to use these mechanisms in dealing with challenging introductions.

More important, I have argued that these response patterns are rooted in historical differences in the management of manufacturing technology, including the organization of technical tasks at the factory level, within the corporation, and between the firm and its outside technical partners. This study identified three related areas of managerial choice that determine

the development of technical capabilities in the manufacturing organization. First was the existence of a multi-faceted, strategy-level management body charged with the guidance of process development activities. In Europe, this body served to coordinate development efforts over time and across facilities. Second was a consistent, top-to-bottom emphasis on the continuous improvement of existing manufacturing processes. This effort showed up plainly in high levels of productivity improvement and quality performance in European divisions, and in the attitudes and assumptions which project participants brought to new process introductions. It was supported by a tradition of cross-boundary problem solving between the manufacturing organization and outside suppliers of technology. Finally, the third area of managerial choice which differed across regions was the system for building technical competence in the manufacturing organization. In Italy in particular, continuous managerial emphasis on personnel development, cross-training, and cross-fertilization appeared to have resulted in a workforce which brought unusual capabilities to both ongoing process improvement and new process introductions.

This paper leaves many questions unanswered, and perhaps suggests some new ones. First, it must be remembered that this study was confined to a single company. No attempt has been made explicitly to link managerial choices in the Company's different operating units to broader political, economic, and cultural forces in Europe and the U.S. Therefore it is impossible to generalize these findings to other organizations in the countries or regions involved. An important next step in the research would be to compare these findings to work by researchers examining more general patterns in these and other geographic regions. An interesting second step would be to expand the existing study to a larger sample of companies and industries. On the other hand, the findings reviewed in this paper are broadly consistent with conclusions reached by other authors who have compared the development of manufacturing technology in different national contexts, including Piore and Sabel (1984), Jaikumar (1985) and Dertouzos et al. (1989).

More important, this study suggests that a company's strategic guidance

of its manufacturing technology, and its attention to the long-term development of people and processes, are intimately linked to its ability to utilize new manufacturing technologies. This interdependence has been suggested by analysts and industry observers (e.g. Schonberger, 1986; Manufacturing Studies Board, 1986; Thurow, 1987), however there has been little empirical evidence to support assertions[9] and little clinical detail on the effects of different managerial choices in these areas. I have tried in this paper to show how historical choices about technology influence not only a firm's current standing but also its ability to redefine itself through the introduction of new technologies in the future.

More research is merited which explores these connections within the global corporation. The questions involved are important for increasing our understanding of the process of technological change in manufacturing organizations. Further, these issues are of vital practical concern in light of the serious questions which now surround the global competitiveness of the U.S. manufacturing sector.

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[9] An important exception to this is work by Hayes and Clark (1985) and their colleagues, who showed that plants which were "better managed" in terms of quality performance and inventory levels were also able consistently to introduce new equipment with less disruption than more "poorly managed" plants.

REFERENCES

Abernathy, William J. (1978) The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry, Baltimore: Johns Hopkins University Press.

Abernathy, William J. and Kim B. Clark (1985) "Innovation: Mapping the Winds of Creative Destruction" Research Policy, 14, 3-22.

Allen, T.J. (1977) Managing the flow of technology, Cambridge MA: MIT Press.

Allen, T.J., D.M.S. Lee and M.L. Tushman (1980) "R&D performance as a function of communication, project management, and the nature of work" IEEE Transactions on Engineering Management, Vol. EM-27, 2-12.

Beckman, Sara (1986) "Manufacturing Flexibility and Organization Structure", unpublished Ph.D. thesis, Stanford University.

Bright, James R. (1958) Automation and Management Boston, MA: Harvard Business School Division of Research.

Chew, W. Bruce (1985) "Productivity and Change: Understanding Productivity at the Factory Level" paper for the 75th Anniversary Colloquium of the Harvard Business School.

Clark, Kim B. (1988) "Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development" Harvard Business School Working Paper 88-069

Dertouzos, Michael L., Richard K. Lester and Robert M. Solow (1989) Made in America: Regaining the Productive Edge Cambridge MA: MIT Press.

Duncan, Robert B. (1976) "The Ambidextrous Organization: Designing Dual Structures for Innovation", in Ralph H. Kilmann, Louis R. Pondy, and Dennis P. Slevin (eds.) the Management of Organization Design, Volume I, 167-188.

Ettlie, John and Albert Rubenstein (1980) "Social Learning Theory and the Implementation of Production Innovations" Decision Science 11 (4) (October) 648-668.

Evan, William M. (1966) "The Organization-Set: Toward a Theory of Interorganizational Relationships" in James D. Thompson (ed.) Approaches to Organization Design Pittsburgh: University of Pittsburgh Press.

Galbraith, Jay (1973) Designing Complex Organizations Reading, MA: Addison Wesley.

Gerwin, Donald (1981) "Control and Evaluation in the Innovation Porcess: the Case of Flexible Manufacturing Systems" IEEE Transactions on Engineering Management, vEM-28, no 3, 61-70.

Graham, Margaret B.W. and Stephen R. Rosenthal (1986) "Institutional Aspects of Process Procurement for Flexible Machining Systems," Manufacturing Roundtable Research Report Series, Boston University, Boston, MA.

Gunn, Thomas G. (1987) Manufacturing for Competitive Advantage Cambridge, MA: Ballinger Publications.

Hayes, Robert H. and Kim B. Clark (1985) "Exploring the Sources of Productivity Differences at the Factory Level," in Clark, K.B., Hayes, and Lorenz (eds.) The Uneasy Alliance Boston, MA: Harvard Business School Press.

Imai, K., I. Nonaka and H. Takeuchi (1984) "Managing New Product Development: How Japanese Companies Learn and Unlearn" in Clark, Hayes, and Lorenz (eds.) The Uneasy Alliance Boston, MA: Harvard Business School Press.

Jackson, Barbara Bund (1983) Multivariate Data Analysis Homewood, IL: Richard D. Irwin.

Jaikumar, Ramchandran (1986) "Postindustrial Manufacturing," Harvard Business Review 64 (6) (November-December) 69-76.

Kazanjian, Robert K. and Robert Drazin (1986) "Implementing Manufacturing Innovations: Critical Choices of Structure and Staffing Roles" Human Resources Management 25:30, 285-403.

Kimberly, John R. (1981) "Managerial Innovation" Paul C. Nystrom and William Starbuck, (eds.) Handbook of Organizational Design Vol. 1, Oxford, England: Oxford University Press Vol. 1, 84-104.

Landau, M. (1969) "Redundancy, rationality, and the problem of duplication and 'overlap'" Public Administration Review, Vol. 29, 346-358.

Leonard-Barton, Dorothy (1987) "Implementation as Mutual Adaptation of Technology and Organization" working paper 88-016, Harvard University Graduate School of Business Administration.

Lynn, Leonard H, How Japan Innovates - A Comparison with the U.S. in the Case of Oxygen Steelmaking Boulder Co, Westview Press, 1982.

Majchrzak, Ann (1988) The Human Side of Factory Automation San Francisco, Jossey-Bass.

Manufacturing Studies Board (1986) Toward a New Era in U.S. Manufacturing: The Need for a National Vision Washington, D.C.: National Research Council

March, James G. and Herbert Simon (1958) Organizations New York: John Wiley and Sons.

Nutt, Paul C. (1986) "Tactics of Implementation" Academy of Management Journal 29, no. 2, 230-261.

Perrow, Charles (1967) "A Framework for the Comparative Analysis of Organizations" American Sociological Review 32 (2) (April) 194-208.

Piore, Michael and Charles F. Sabel (1984) The Second Industrial Divide New York, Basic Books.

Rice, Ronald E. and Everett Rogers (1980) "Reinvention in the Innovation Process," Knowledge 1 (4) 499-514.

Rogers, Everett M. (1982) Diffusion of Innovations (Third Edition) New York: The Free Press.

Sapolsky, Harvey (1967) "Organizational Structure and Innovation" Journal of Business 40 (7) 497-510.

Schonberger, Richard (1986) World Class Manufacturing New York: The Free Press.

Thompson, James D. (1967) Organizations in Action New York: McGraw Hill.

Thurow, Lester C. (1987) "A Weakness in Process Technology" Science v 238, December, 1659-1663.

Tushman, M.L. and P. Anderson (1986) "Technological discontinuities and organizational environments" Administrative Science Quarterly, Vol. 31, 439-465.

Tyre, Marcie J. and Oscar Hauptman (1989) "Technological Change in the Production Process: Organizational Implications and Responses" Working paper #3050-89-BPS Cambridge MA: MIT.

Van de Ven, Andrew, (1986) "Central Problems in the Management of Innovation" Management Science 32 (5) 590-607.

Zaltman, Gerald, Robert B. Duncan, and Jonny Holbeck (1973) Innovation in Organizations New York: John Wiley and Sons.

Figure 1

Two Aspects of Technological Process Change

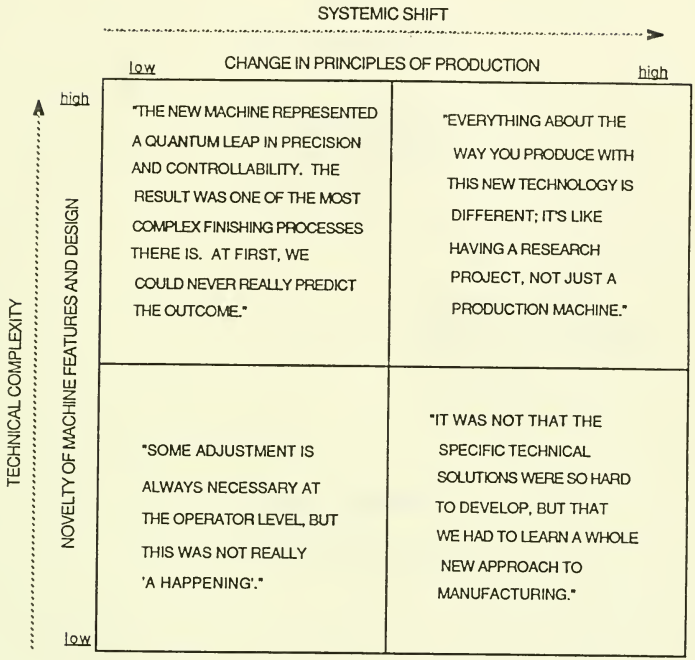
SYSTEMIC SHIFT
low
CHANGE IN PRINCIPLES OF PRODUCTION
high
TECHNICAL COMPLEXITY
NOVELTY OF MACHINE FEATURES AND DESIGN
high
low
"THE NEW MACHINE REPRESENTED A QUANTUM LEAP IN PRECISION AND CONTROLLABILITY. THE RESULT WAS ONE OF THE MOST COMPLEX FINISHING PROCESSES THERE IS. AT FIRST, WE COULD NEVER REALLY PREDICT THE OUTCOME."
"EVERYTHING ABOUT THE WAY YOU PRODUCE WITH THIS NEW TECHNOLOGY IS DIFFERENT; IT'S LIKE HAVING A RESEARCH PROJECT, NOT JUST A PRODUCTION MACHINE."
"SOME ADJUSTMENT IS ALWAYS NECESSARY AT THE OPERATOR LEVEL, BUT THIS WAS NOT REALLY 'A HAPPENING'."
"IT WAS NOT THAT THE SPECIFIC TECHNICAL SOLUTIONS WERE SO HARD TO DEVELOP, BUT THAT WE HAD TO LEARN A WHOLE NEW APPROACH TO MANUFACTURING."

Figure 2

Model of Process Change

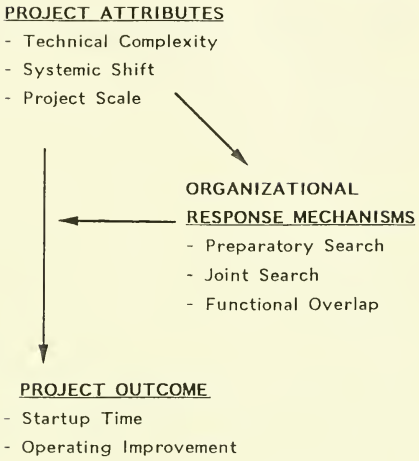

Table 1

Correlation Matrix of Project Attributes, Response Mechanisms, and Outcomes

(n=48)

	TECH. COM.	SYSTEM. SHIFT	PROJECT SIZE	PREP. SEARCH	JOINT SEARCH	FUNCT. OVERLAP	STARTUP TIME
SYSTEMIC SHIFT	#						
PROJECT SIZE	.12	-.11					
PREP. SEARCH	-.09	.23*	.15				
JOINT SEARCH	.37**	.30**	.05	.05			
FUNCT. OVERLAP	-.05	.60**	.42**	.39**	.15		
STARTUP TIME	.52**	.35*	.07	-.39**	.04	.06	
OPERAT. IMPROVEMENT	-.21*	.10	-.01	.52**	.17	.24*	-.63**

#Orthogonal factors.

**Pearson correlation significant at $p<0.05$; *$p<.10$.

Table 2

Project Attributes, Response Mechanisms and Project Performance

A. Effect on **STARTUP TIME**

Independent Variables:

	TECHNICAL COMPLEXITY	SYSTEMIC SHIFT	PROJECT SIZE	PREP-ARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP
I	.49** (.12)	.32** (.12)	.05 (.12)	--	--	--
					R^2=.33 (df=45); F=8.7 (p<.001)	
II	.54** (.09)	.74** (.13)	.32** (.11)	-.41** (.09)	-.35** (.10)	-.33** (.14)
					R^2=.64 (df=42); F=15.2 (p<.001)	

B. Effect on **OPERATING IMPROVEMENT**

	TECHNICAL COMPLEXITY	SYSTEMIC SHIFT	PROJECT SIZE	PREP-ARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP
III	-.22 (.15)	.12 (.15)	.02 (.15)	--	--	--
					R^2=.00 (df=45); F=0.9 (NS)	
IV	-.25* (.13)	-.27 (.18)	-.23 (.16)	.47** (.13)	.30** (.14)	.28 (.20)
					R^2=.30 (df=42); F=4.43 (p<.005)	

Regression coefficients are standardized to facilitate comparison of effect sizes;
Standard errors are shown in parentheses.
** = significant at .05 confidence level; * = .10 confidence level.

Table 3

Regional Differences in Means: Europe and the U.S.

	MEAN		STANDARD DEVIATION	
	Europe	U.S.	Europe	U.S.
	(n=31)	(n=17)		
Startup Time	19.9	26.9	11.6	17.4
Technical Performance	14.0	10.0	7.4	6.4
Technical Complexity	.02	-.06	.94	.77
Systemic Shift	-.05	.11	1.01	.98
Project Size($000,000)	1.52	.50	1.46	.52
Preparatory Search	14.7	12.2	5.6	4.8
Joint Search	10.3	9.1	5.3	4.0
Functional Overlap	2.5	1.3	1.7	1.3

NOTES: Comparative figures are shown to provide a general impression of the differences in scores across regions. T-statistics or other tests of statistical significance are not considered informative, given the relatively small size of the subsamples and the relatively large number of comparisons considered.

Differences in means between Germany (n=17) and Italy (n=14) were also examined, however no consistent or significant patterns were revealed.

Table 4

Regional Differences in Startup Time and Operating Improvement

A. Effect on **STARTUP TIME**

Independent Variables:

	TECHNICAL COMPLEXITY	SYSTEMIC SHIFT	PROJECT SIZE	PREP-ARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP	U.S. DUMMY
I	.50** (.11)	.30** (.11)	.16 (.12)	--	--	--	.30** (.12)
					R^2=.40 (df=44); F=8.7 (p<.001)		
II	.54** (.09)	.69** (.14)	.33** (.07)	-.39** (.09)	-.33** (.10)	-.28* (.15)	.11 (.10)
					R^2=.64 (df=41); F=13.2 (p<.001)		

B. Effect on **OPERATING IMPROVEMENT**

	TECHNICAL COMPLEXITY	SYSTEMIC SHIFT	PROJECT SIZE	PREP-ARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP	U.S. DUMMY
III	-.23 (.14)	.13 (.14)	-.10 (.15)	--	--	--	-.33** (.15)
					R^2=.10 (df=44); F=2.0 (NS)		
IV	-.25* (.13)	-.20 (.19)	-.25 (.15)	.45** (.13)	.27** (.14)	.20 (.20)	-.16 (.10)
					R^2=.31 (df=41); F=4.0 (p<.005)		

Regression coefficients are standardized to facilitate comparison of effect sizes;
Standard errors are shown in parentheses.
** = significant at .05 confidence level; * = .10 confidence level.

Table 5

Organizational Responses to Technological Change

[1] Projects Undertaken in **EUROPEAN PLANTS** (n=31)

	Organizational Response		
Project Attributes	PREPARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP
TECHNICAL COMPLEXITY	-.08	.51**	.01
SYSTEMIC SHIFT	.27*	.29*	.39**
PROJECT SCALE	.05	.03	.26*

[2] Projects Undertaken in **U.S. PLANTS** (n=17)

	Organizational Response		
Project Attributes	PREPARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP
TECHNICAL COMPLEXITY	-.25	-.11	.31
SYSTEMIC SHIFT	-.15	.27	.62**
PROJECT SCALE	-.56**	.04	.04

Spearman correlations: * = significant at $P < .10$; ** = $P < .05$

Appendix 1

Aggregate Scales of Technological Change

SCALE NAME	DEFINITION	NUMBER OF VARIABLES	CRONBACH ALPHA
Technology Newness	Newness of technical features relative to technology previously available	4	.86
New To Plant	Familiarity of technical features relative to equipment existing in the plant at the time of the introduction	4	.83
New Base	The degree to which the new technology is based on technical or operating principles new to the plant or the company	4	.77
Ongoing Development	The degree to which the new technology is a prototype installation	3	.65
New Product	The degree of change in product specifications introduced with the new equipment	3	.64
Required Performance	The stringency of performance requirements (cost and quality) relative to existing standards	4	.65

Appendix 2

Contribution of Scales to
Technical Complexity and Systemic Shift Factors

	Contribution to Factor 1: **Technical Complexity**	Contribution to Factor 2: **Systemic Shift**	
Aggregate Scale:			
1. New Technology	**.84**	.12	
2. New to Plant	**.54**	**.57**	
3. New Base	.07	**.99**	
4. Ongoing Development	**.52**	.31	
5. New Product	.34	.17	
6. Performance	**.44**	.02	
Variance Explained by Factor:	.27	.26	total=.53

Note: Factor analysis used principal analysis and varimax rotation.

Appendix 3

Derivation of Organizational Response Variables

1. Preparatory Search

What role did technical support and production personnel play in the following activities before the equipment arrived at the factory?

1. Propose purchase of the new equipment.
2. Developing new technological concepts.

(1-5 scale: 1 = not involved; 2 = were informed; 3 = gave advice; 4 = major support; 5 = fully responsible.)

3. Describe any studies undertaken by plant personnel prior to delivery of the new equipment. (Interview item, with questionnaire commentary.)

(1 = no studies; 3 = some study, but not unusual amount; engineering personnel performed some analyses; 5 = intensive study; we made a major tool life project, and several people were assigned; we made a large effort to resolve problems in the systems choice before we even ordered the equipment...)

4. Describe the process of pretesting the equipment at the vendor (or, where applicable, in the plant) prior to delivery (or to startup). (Interview item, with questionnaire commentary.)

(1 = We had a runoff test, but it was perfunctory; the vendor had everything set up just right, and we were not allowed to change the conditions; the people we sent to the qualifying test did not know what to look for; 5 = We did extensive runoff testing at the vendor's, and we refused to accept the equipment until it worked to our standards; once we received the equipment, we set it up off-line and did extensive testing or routines and tooling.)

Scale alpha = .67

2. Joint Search

1. How helpful were people from the following groups during this introduction?
   a. Equipment vendor or in-house development center?
   b. Personnel from sister plants?
   c. Outside advisors?
   d. Technical experts from division technical center?

(1-5 scale: Made critical contributions ___ no real contribution.)

2. Where did people get the know-how to accomplish the introduction of the new equipment -- how true are the following statements?

a. Outside experts provided guidance.
b. Training by the vendor provided essential know-how.
(1-5 scale: True for this introduction _____ Not at all true.)

3. Describe the role of outside experts in the startup process.
(Interview item, with questionnaire commentary)

(1 = Not a partner in the problem solving process; sold the equipment and the normal services (such as initial installation help, replacement parts but was not really part of the project team; 5 = Part of the problem solving team; the vendor gave us lots of important ideas, we discussed many of our problems with him; I learned a lot about this technology by working with the supplier; the expert from the head office came to this plant and worked closely with me and my colleagues, he was an important partner in the introduction project.)

Scale alpha = .79

3. Functional Overlap

Primary information came from:

1. Participants' sketches of the "people and project structure" and their commentary of the sketch;

2. Participants' descriptions of the problem solving process: who was involved and the modes of communication and contribution;

Information was coded for mechanisms listed below:

Mechanisms for Mutual Adjustment and Feedback (1)

- Individuals from different functions work together directly to identify and solve problems in the new process.

- A manager who is not directly involved with the introduction plays a linking role between functions.

- A project manager(2) has ongoing responsibility for both technical and production activities in the plant or department.

- The introduction is organized as a special interfunctional task team.

- The introduction is one of many activities performed by a multi-level, multi-functional task team.

- One or more individuals act as liaisons between functions (e.g. an engineer participates directly on the production line; a production operator participates in an engineering study).

- Permanent or temporary transfer of personnel across functional areas links the production area with the locus of technological decision-making.- (3)

- The introduction takes place within a semi-autonomous, multi-functional unit within the plant.

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(1) Descriptions adapted from Galbraith (1973).
(2) Formal or informal designation; multiple managers possible.
(3) Only transfers directly related to the introduction are considered. Previous transfers undertaken as a general policy are not included.

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